DISTRIBUTED SYSTEMS

BitTorrent

BitTorrent

- Widely used download technology

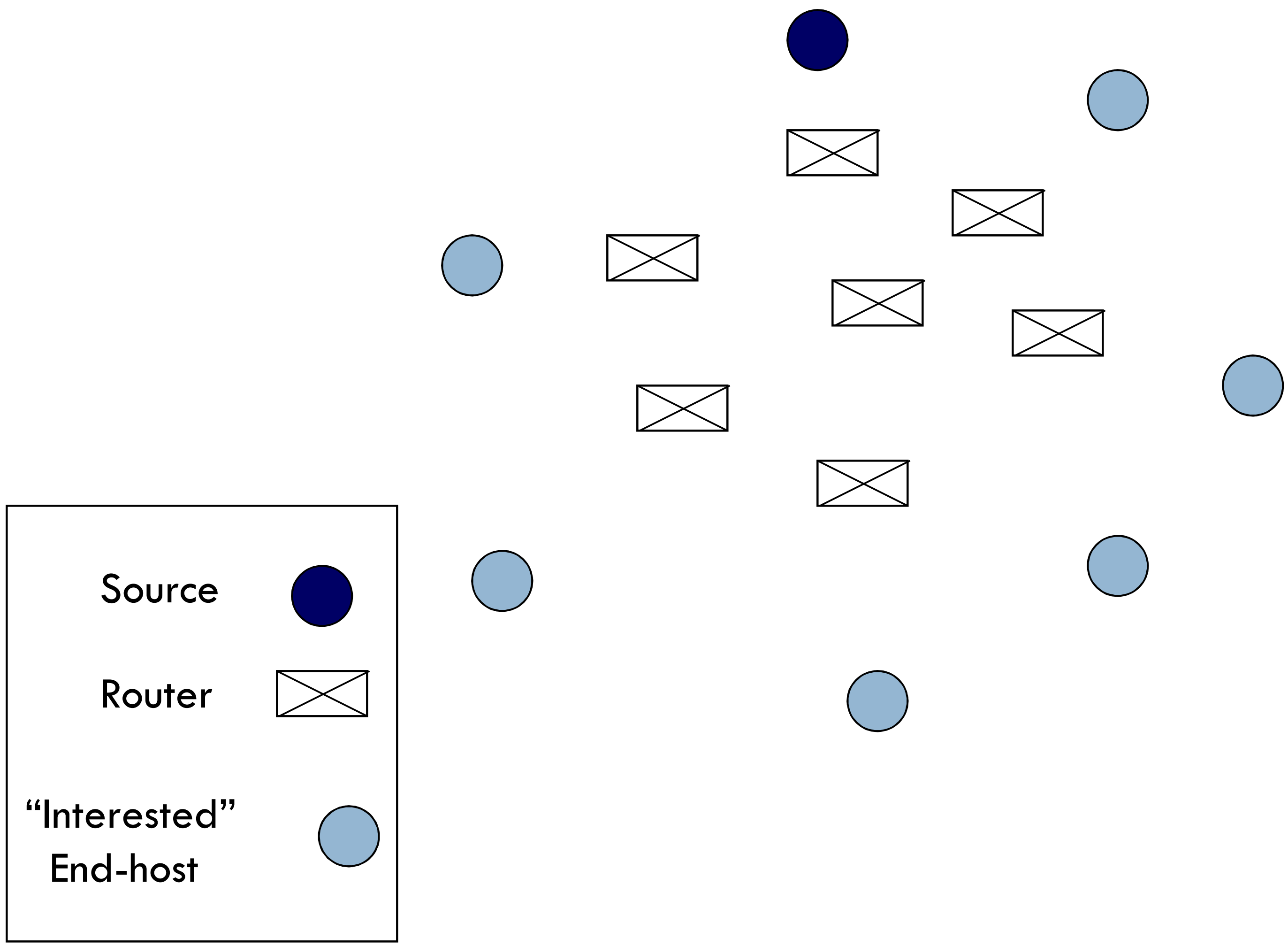
- Implementations specialized for setting
  - Some focus on P2P downloads, e.g. patches
  - Others focus on use cases internal to corporate clouds

BitTorrent

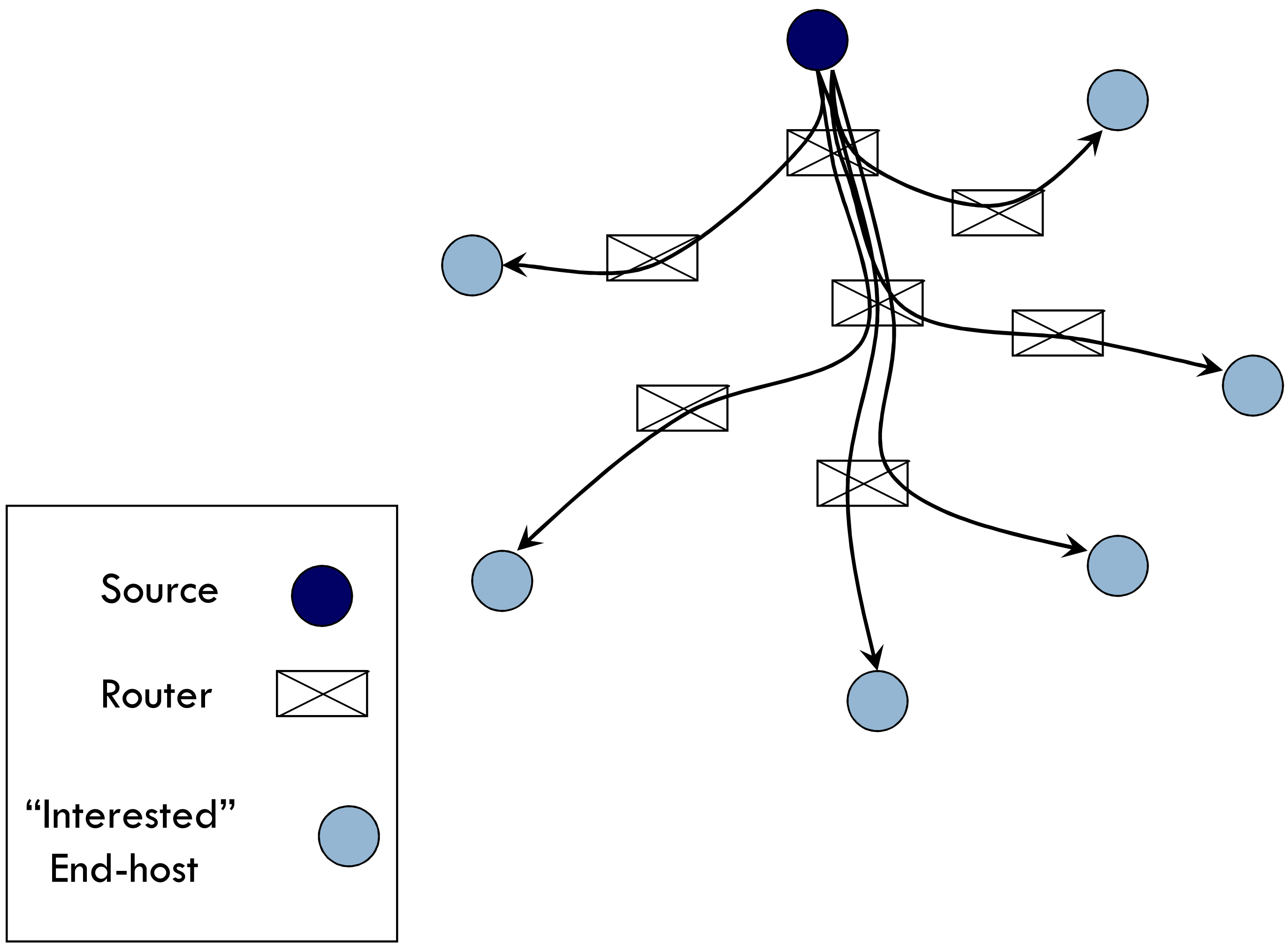
- The technology known for three reasons:
  - A standard that BitTorrent client systems follow
  - Some existing clients, e.g. the free Torrent client, PPLive
  - A clever idea: using “tit-for-tat” mechanisms to reward good behavior and to punish bad behavior
- This third aspect is especially intriguing!

The basic BitTorrent Scenario

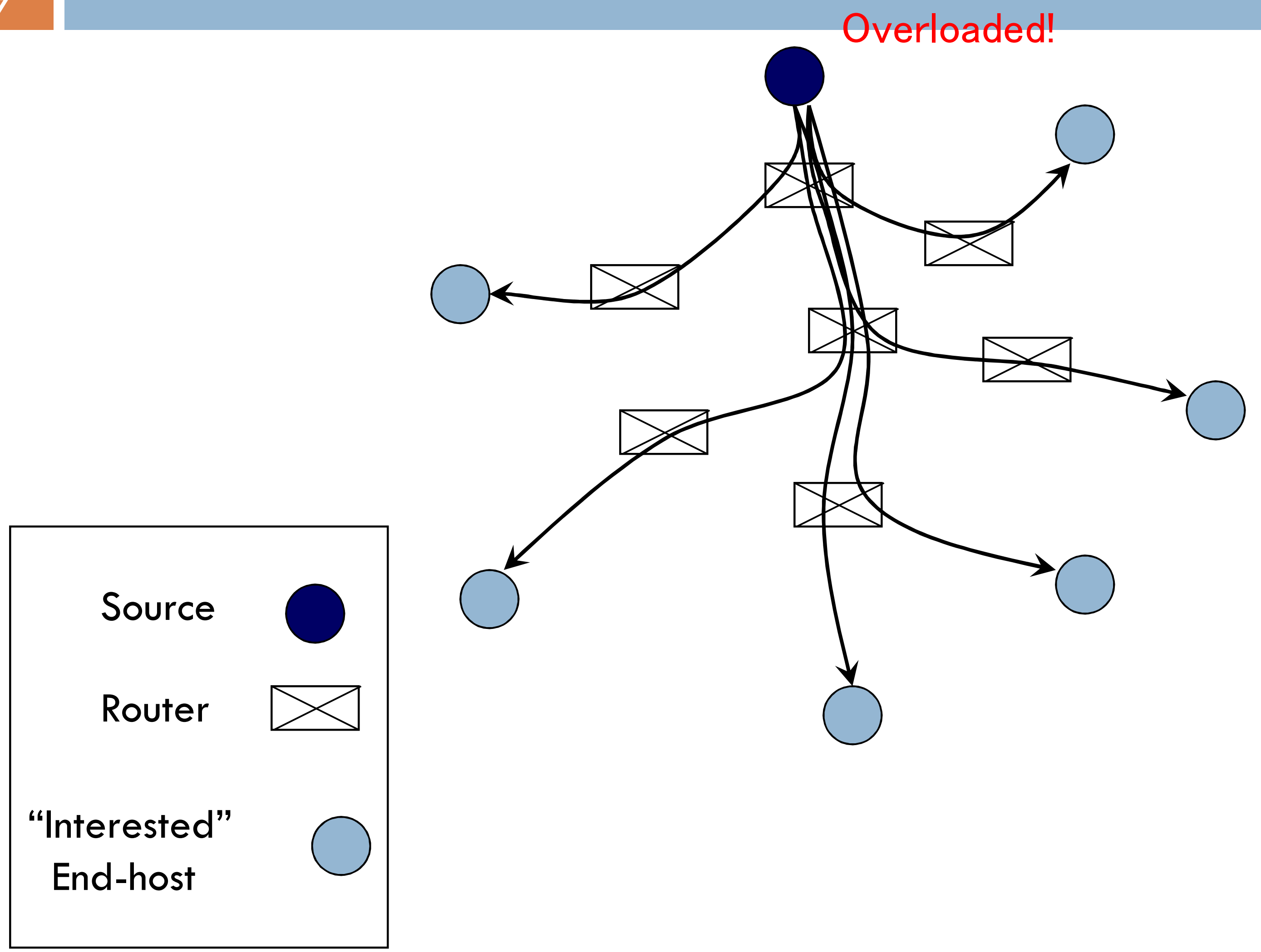
- Millions want to download the same popular huge files (for free)
  - ISO's
  - Media (the real example!)
- Client-server model fails
  - Single server fails
  - Can't afford to deploy enough servers


Source
Router
"Interested"
End-host

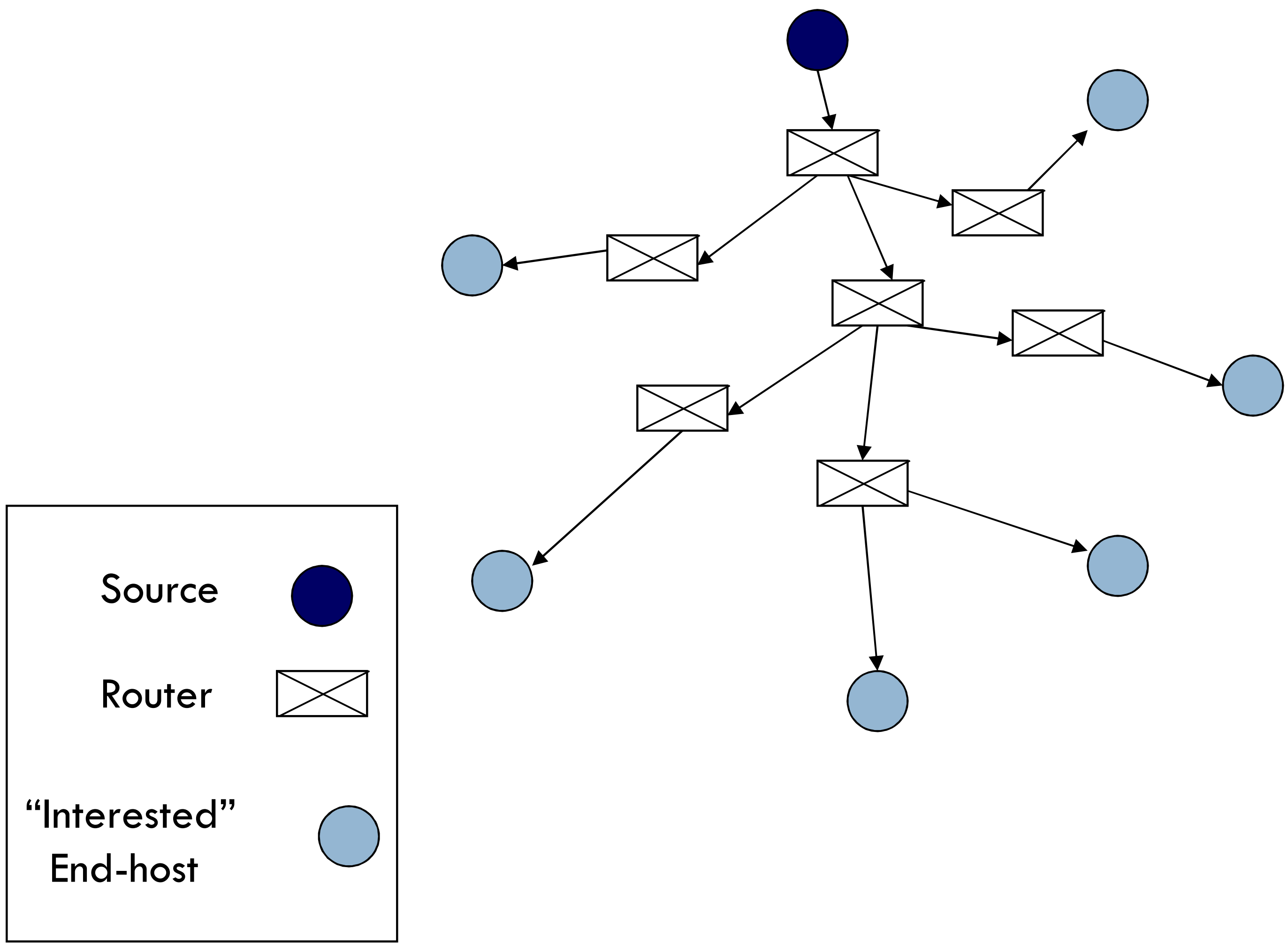
Client-Server



Client-Server



Why not use IP multicast?



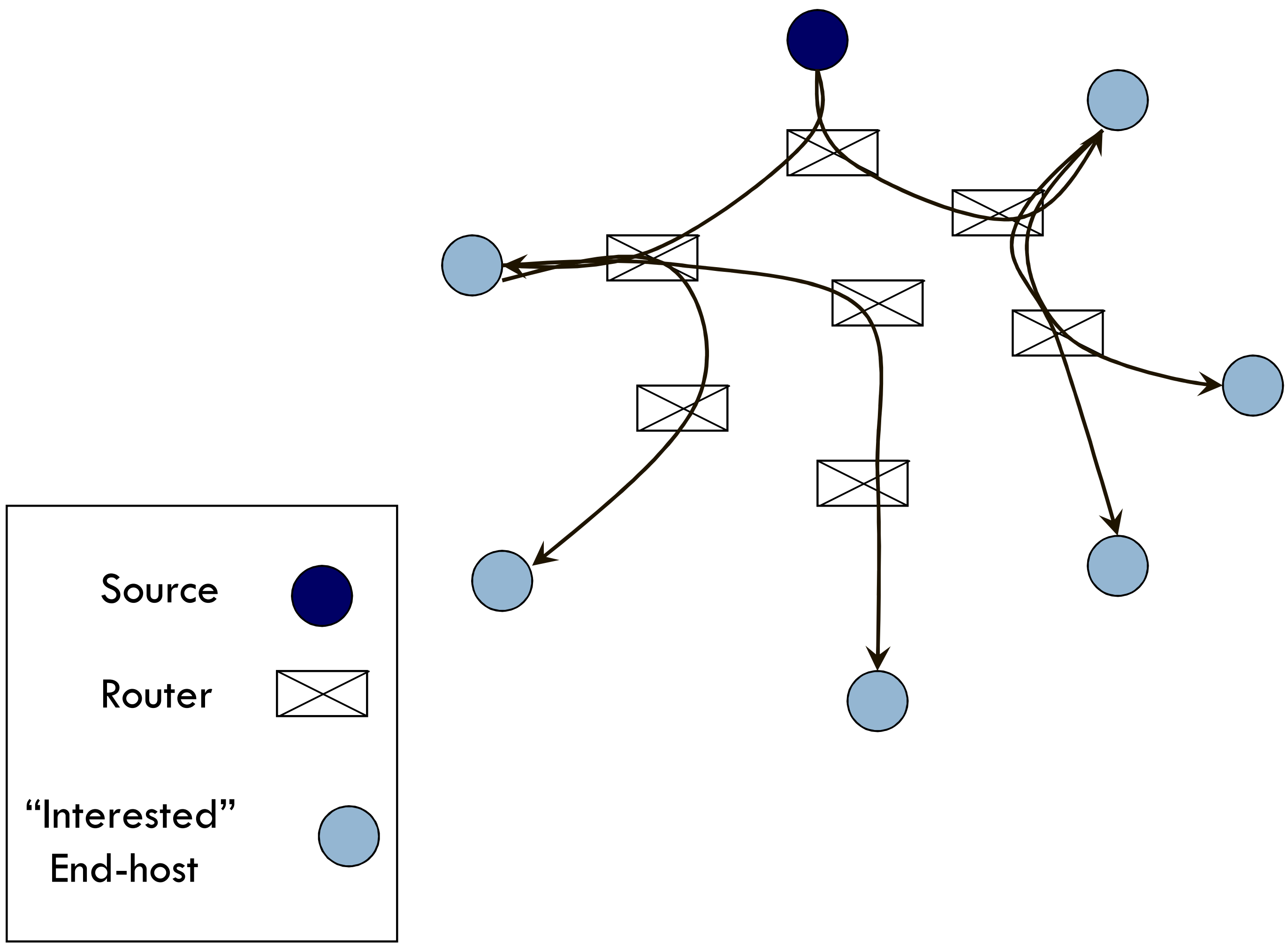
Why not use IP Multicast?

- IP Multicast not a real option in general WAN settings
  - Not supported by many ISPs
  - Most commonly seen in private data centers
- Alternatives
  - End-host based Multicast
  - BitTorrent
  - Other P2P file-sharing schemes

End-host based multicast

- “Single-uploader” → “Multiple-uploaders”
  - Lots of nodes want to download
  - Make use of their *uploading* abilities as well
  - Node that has downloaded (part of) file will then upload it to other nodes.
  - Uploading costs amortized across all nodes

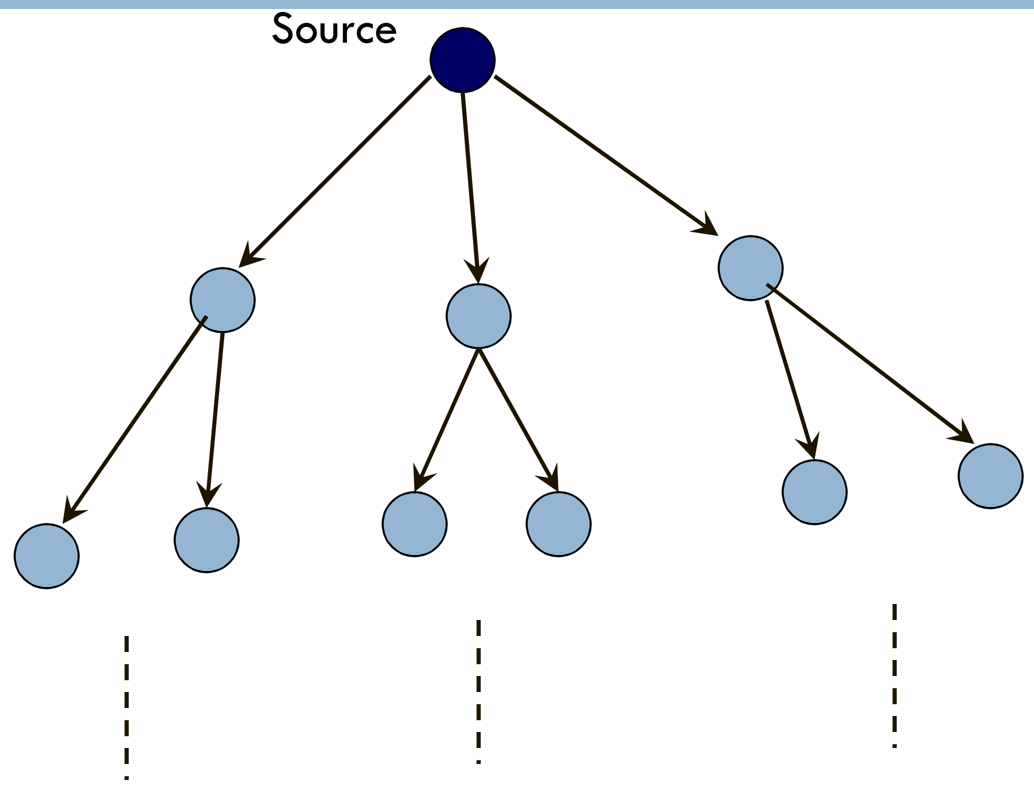
End-host based multicast



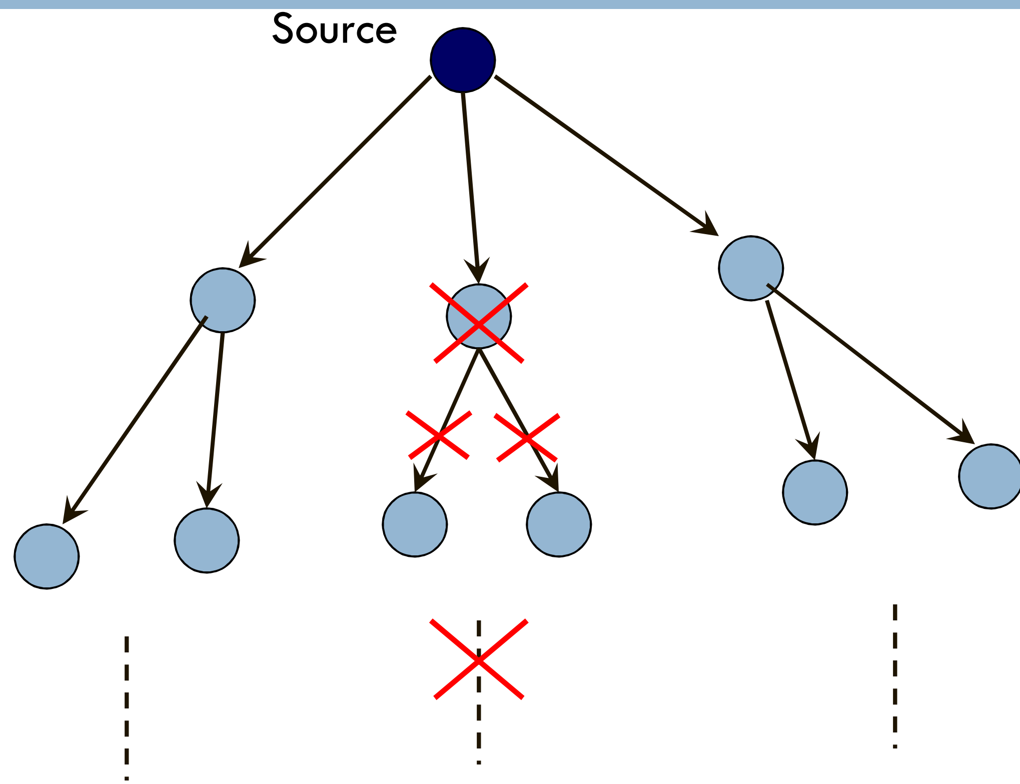
End-host based multicast

- Also called “Application-level Multicast”
- Many protocols proposed
  - Yoid (2000), Narada (2000), Overcast (2000), ALMI (2001)
    - All use single trees
    - Problem with single trees?

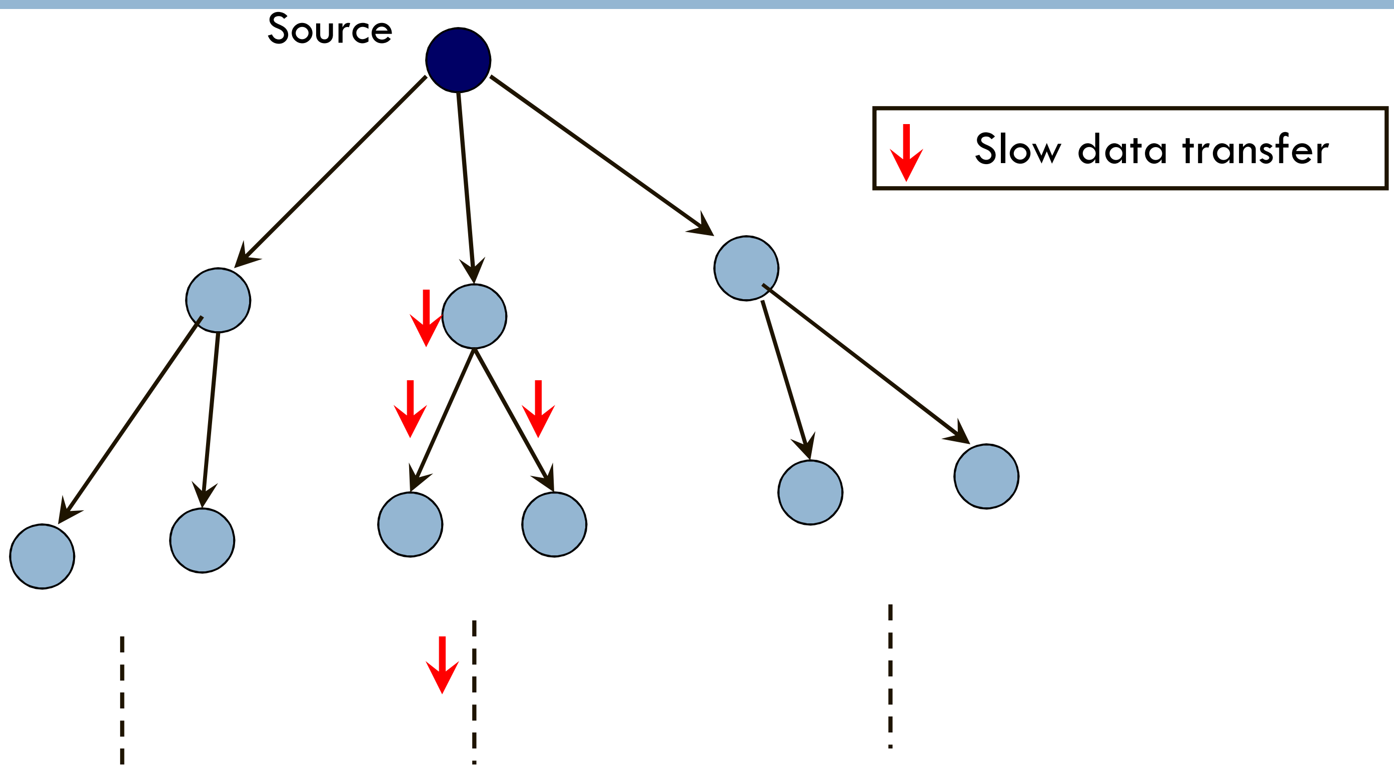
End-host multicast using single tree



End-host multicast using single tree



End-host multicast using single tree



End-host multicast using single tree

- Tree is "push-based" – node receives data, pushes data to children
- Failure of "interior"-node affects downloads in entire subtree rooted at node
- Slow interior node similarly affects entire subtree
- Also, leaf-nodes don't do any sending!
- Though later multi-tree / multi-path protocols (Chunkyspread (2006), Chainsaw (2005), Bullet (2003)) mitigate some of these issues

BitTorrent

- Written by Bram Cohen (in Python) in 2001
- “Pull-based” “swarming” approach
  - Each file split into smaller pieces
  - Nodes request desired pieces from neighbors
    - As opposed to parents pushing data that they receive
  - Pieces not downloaded in sequential order
  - Previous multicast schemes aimed to support “streaming”; BitTorrent does not
- Encourages contribution by all nodes

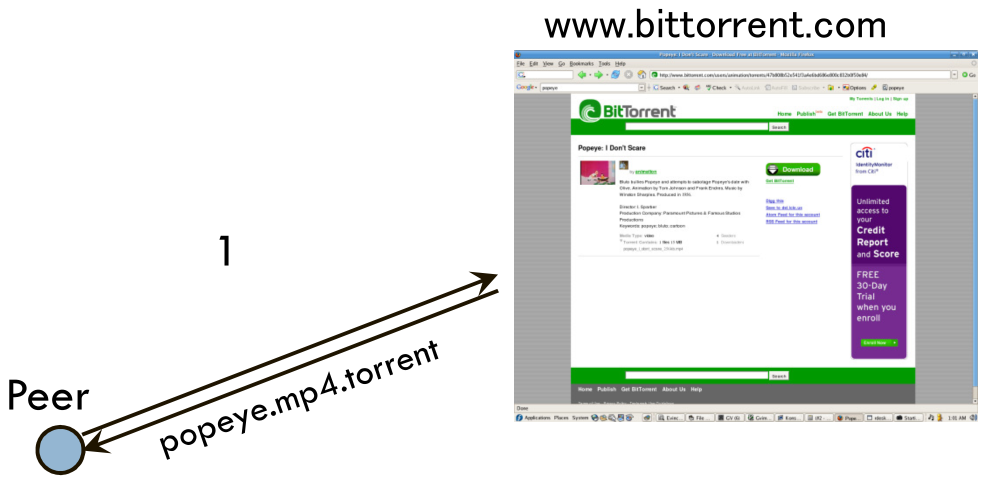
BitTorrent Swarm

- Swarm
  - Set of peers all downloading the same file
  - Organized as a random mesh
- Each node knows list of pieces downloaded by neighbors
- Node requests pieces it does not own from neighbors
  - Exact method explained later

How a node enters a swarm for file “popeye.mp4”

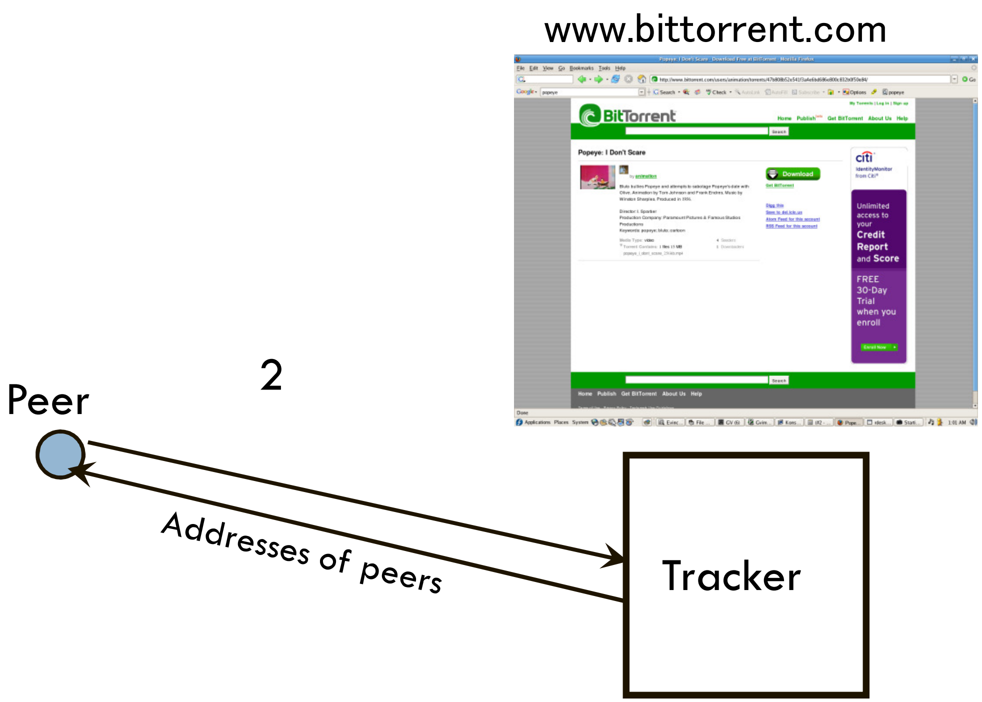
- File popeye.mp4.torrent hosted at a (well-known) webserver
- The .torrent has address of tracker for file
- The tracker, which runs on a webserver as well, keeps track of all peers downloading file

How a node enters a swarm for file "popeye.mp4"



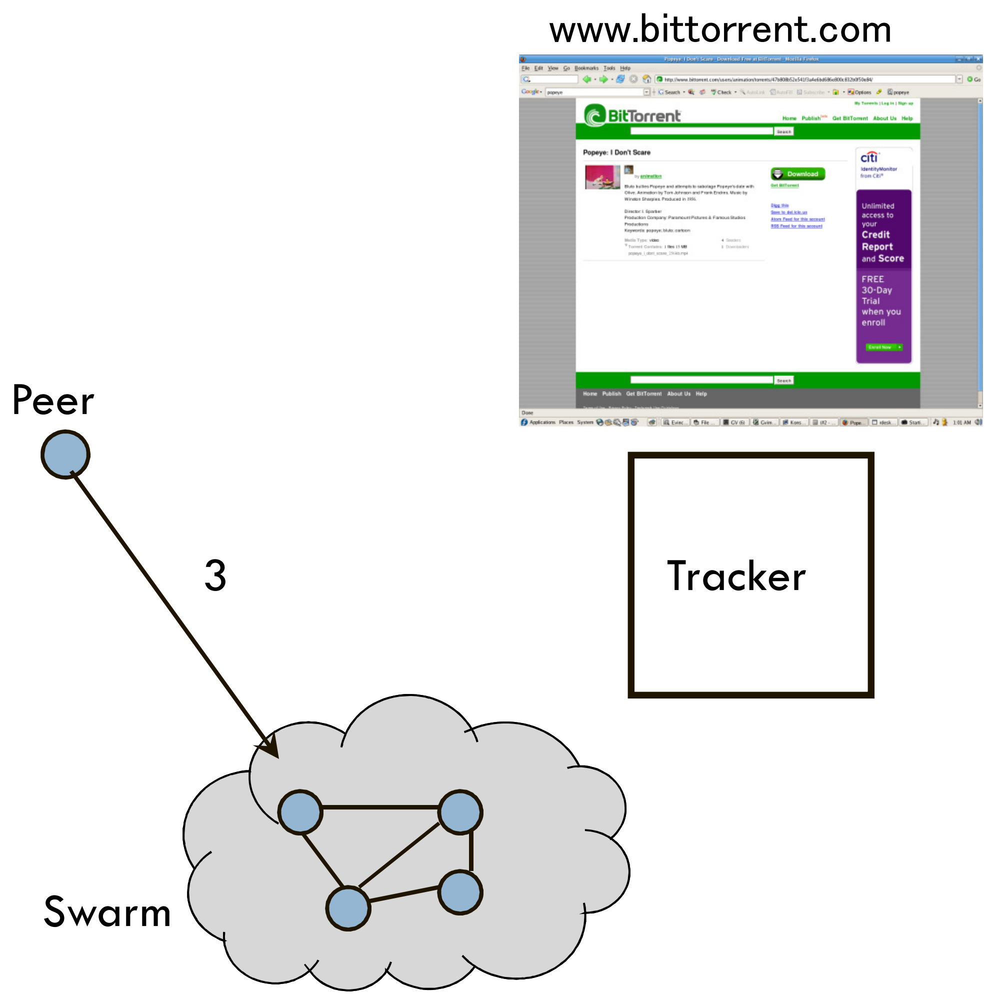
- File popeye.mp4.torrent hosted at a (well-known) webserver
- The .torrent has address of tracker for file
- The tracker, which runs on a webserver as well, keeps track of all peers downloading file

How a node enters a swarm for file “popeye.mp4”



- File popeye.mp4.torrent hosted at a (well-known) webserver
- The .torrent has address of tracker for file
- The tracker, which runs on a webserver as well, keeps track of all peers downloading file

How a node enters a swarm for file "popeye.mp4"



- File popeye.mp4.torrent hosted at a (well-known) webserver
- The .torrent has address of tracker for file
- The tracker, which runs on a webserver as well, keeps track of all peers downloading file

Contents of .torrent file

- URL of tracker
- Piece length – Usually 256 KB
- SHA-1 hashes of each piece in file
  - For reliability
- "files" – allows download of multiple files

Terminology

- Seed: peer with the entire file
  - Original Seed: The first seed
- Leech: peer that's downloading the file
  - Fairer term might have been "downloader"
- Sub-piece: Further subdivision of a piece
  - The "unit for requests" is a subpiece
  - But a peer uploads only after assembling complete piece

Peer-peer transactions: Choosing pieces to request

- Rarest-first: Look at all pieces at all peers, and request piece that's owned by fewest peers
  - Increases diversity in the pieces downloaded
    - avoids case where a node and each of its peers have exactly the same pieces; increases throughput
  - Increases likelihood all pieces still available even if original seed leaves before any one node has downloaded entire file

Choosing pieces to request

- Random First Piece:
  - When peer starts to download, request random piece.
    - So as to assemble first complete piece quickly
    - Then participate in uploads
  - When first complete piece assembled, switch to rarest-first

Choosing pieces to request

- End-game mode:
  - When requests sent for all sub-pieces, (re)send requests to all peers.
  - To speed up completion of download
  - Cancel request for downloaded sub-pieces

Tit-for-tat as incentive to upload

- Want to encourage all peers to contribute
- Peer *A* said to choke peer *B* if it (*A*) decides not to upload to *B*
- Each peer (say *A*) unchokes at most 4 *interested* peers at any time
  - The three with the largest upload rates to *A*
    - Where the tit-for-tat comes in
  - Another randomly chosen (Optimistic Unchoke)
    - To periodically look for better choices

Anti-snubbing

- A peer is said to be snubbed if each of its peers chokes it
- To handle this, snubbed peer stops uploading to its peers
- Optimistic unchoking done more often
  - Hope is that will discover a new peer that will upload to us

Why BitTorrent took off

- Better performance through "pull-based" transfer
  - Slow nodes don't bog down other nodes
- Allows uploading from hosts that have downloaded parts of a file
  - In common with other end-host based multicast schemes

Why BitTorrent took off

- Practical Reasons (perhaps more important!)
  - Working implementation (Bram Cohen) with simple well-defined interfaces for plugging in new content
  - Many recent competitors got sued / shut down
    - Napster, Kazaa
  - Doesn't do "search" per se. Users use well-known, trusted sources to locate content
    - Avoids the pollution problem, where garbage is passed off as authentic content

Pros and cons of BitTorrent

- Pros
  - Proficient in utilizing partially downloaded files
  - Discourages “freeloading”
    - By rewarding fastest uploaders
  - Encourages diversity through “rarest-first”
    - Extends lifetime of swarm
- Works well for “hot content”

Pros and cons of BitTorrent

- Cons
  - Assumes all interested peers active at same time; performance deteriorates if swarm “cools off”
  - Even worse: no trackers for obscure content

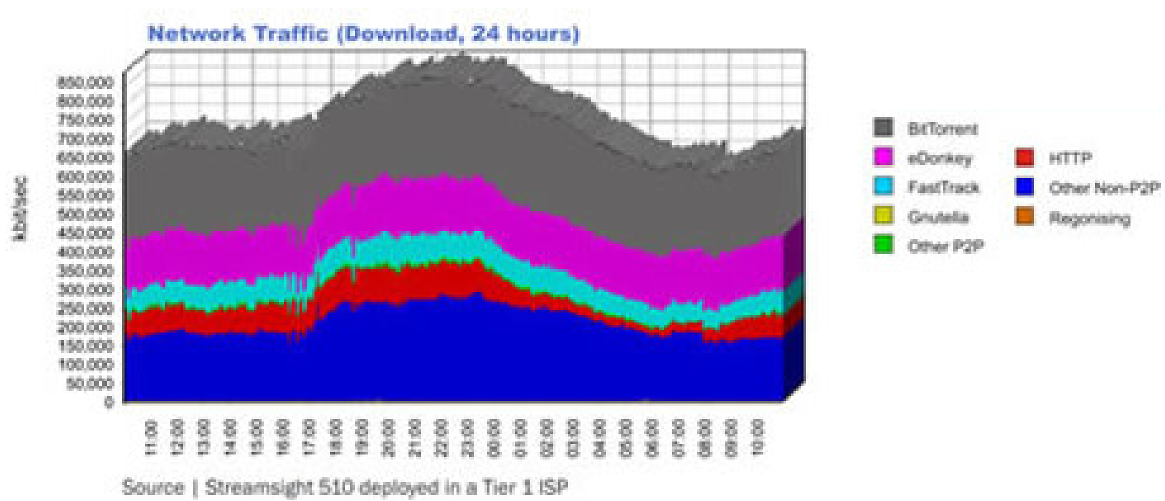
Pros and cons of BitTorrent

- Dependence on centralized tracker: pro/con?
  - ☹ Single point of failure: New nodes can’t enter swarm if tracker goes down
  - Lack of a search feature
    - ☺ Prevents pollution attacks
    - ☹ Users need to resort to out-of-band search: well known torrent-hosting sites / plain old web-search

“Trackerless” BitTorrent

- To be more precise, “BitTorrent without a centralized-tracker”
- E.g.: Azureus
- Uses a Distributed Hash Table (Kademlia DHT)
- Tracker run by a normal end-host (not a web-server anymore)
  - The original seeder could itself be the tracker
  - Or have a node in the DHT randomly picked to act as the tracker

Prior to Netflix “explosion”, BitTorrent dominated the Internet!



(From CacheLogic, 2004)

Why is (studying) BitTorrent important?

- BitTorrent consumes significant amount of internet traffic today
  - In 2004, BitTorrent accounted for 30% of all internet traffic (Total P2P was 60%), according to CacheLogic
  - Slightly lower share in 2015 (~25-28% due to Netflix, YouTube, and other video streaming services) but still significant
  - BT always used for legal software (linux iso) distribution too
  - Recently: legal media downloads (Fox)
- Used within data centers to exchange files

BitTorrent Research

- BitTorrent's success led to flurry of research
  - Performance measurement
  - Complete decentralization (remove centralized points such as tracker)
  - Incentives
    - Protocol can be gamed
    - Major challenge in distributed systems: given a set of nodes, each in different administrative domains, design system such that nodes follow the recommended protocol
      - i.e., have incentive NOT to deviate from it
      - Accountability mechanism for deviating nodes

Example finding from a 2002 U-Wash study

- Study showed that most BitTorrent streams “fail”
  - Found that the number of concurrent users is often too small, and the transfer too short, for the incentive structure to do anything
  - No time to “learn”
- Paper’s suggestion: add a simple history mechanism
- Behavior from yesterday can be used today.
  - this ignores “dynamics” seen in the Internet…

BAR Gossip

- Work done at UT Austin looking at *gossip* model
- They ask what behaviors a node might exhibit
  - Byzantine: the node is malicious
  - Altruistic: The node answers every request
  - Rational: The node maximizes own benefit
- Under this model, is there an optimal behavior?
  - Designed a video streaming service for nodes in different administrative domains

[BAR Gossip. Harry C. Li, Allen Clement, Edmund L. Wong, Jeff Napper, Indrajit Roy, Lorenzo Alvisi, Michael Dahlin. OSDI 2006]

Basic strategy

- They assume cryptographic keys (PKI)
  - Used to create signatures: detect and discard junk
  - Also employed to prevent malfactor from pretending that it sent messages but they were lost in network

- This is used to create a scheme that allows nodes to detect and punish non-compliance

Key steps in BAR Gossip

1. *History exchange*: two parties learn about the updates the other party holds
2. *Update exchange*: each party copies a subset of these updates into a *briefcase* that is sent, encrypted, to the other party. Two cases:
   - *Balanced exchange* for normal operation
   - *Optimistic push* to help one party catch up
3. *Key exchange*, where the parties swap the keys needed to access the updates in the two briefcases.

Obvious concern: Failed key exchange

- What if a rational node chooses not to send the key (or sends an invalid key)?
  - Can't "solve" this problem; they prove a theorem
  - But by tracking histories, BAR gossip allows altruistic and rational nodes to operate *fairly enough*
- Central idea is that the balanced exchange should reflect the quality of data exchanged in past
  - This can be determined from the history and penalizes a node that tries to cheat during exchange
  - Nash equillibrium strategy is to send the keys, so rational nodes will do so!

Outcomes achieved

- BAR gossip protocol provides good convergence as long as:
  - No more than 20% of nodes are Byzantine
  - No more than 40% collude.
- Generally seen as the “ultimate story” for BitTorrent-like schemes

Insights gained?

- Collaborative download schemes can improve download speeds very dramatically
  - They avoid sender overload
  - Are at risk when participants deviate from protocol
  - Game theory suggests possible remedies
- BitTorrent is a successful and very practical tool
  - Widely used inside data centers
  - Also popular for P2P downloads
  - In China, PPLive media streaming system very successful and very widely deployed

References

- BitTorrent
  - "Incentives build robustness in BitTorrent", Bram Cohen
  - BitTorrent Protocol Specification: http://www.bittorrent.org/protocol.html
- Poisoning/Pollution in DHT's:
  - "Index Poisoning Attack in P2P file sharing systems"
  - "Pollution in P2P File Sharing Systems"